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Full Length Article

The relationship between motor performance and parent-rated executive functioning in 3- to 5-year-old children: What is the role of confounding variables?

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ABSTRACT

It is generally agreed that motor performance and executive functioning (EF) are intertwined. As the literature on this issue concerning preschool children is scarce, we examined the relationship between motor performance and parent-rated EF in a sample of 3- to 5-year-old children with different levels of motor skill proficiency, while controlling for age, gender, socio-economic status (SES), and attention-deficit-hyperactivity disorder (ADHD) symptomatology. EF was reported by parents of 153 children (mean age 4 years 1 months, SD 8 months; 75 male) by means of the Behaviour Rating Inventory of Executive Function–Preschool version (BRIEF-P). Parent-reported ADHD symptoms were assessed using the Hyperactivity-Inattention subscale of the Strengths and Difficulties Questionnaire3–4. In addition, the children performed the Movement Assessment Battery for Children–2 (MABC–2). Several weak to moderate relationships were found between the MABC–2 Total Score and the EF subscales. Once other variables such as age, gender, SES, and ADHD symptomatology were taken into account, the only BRIEF-P subscale that was associated with the MABC–2 Total Score was the Working Memory subscale. Compared to their typically developing peers, children who are at risk for motor coordination difficulties ($\leq$ the 16th percentile on the MABC–2) performed poorly on the Working Memory subscale, which confirms the results of the regression analyses. The at risk group also performed significantly worse on the Planning/Organize subscale, however. This is one of the first studies investigating the relationship between motor performance and parent-rated EF in such a young age group. It shows that the relationship between motor performance and EF in young children is complex and may be influenced by the presence of confounding variables such as ADHD symptomatology.

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1. Introduction

Early in life, children go through a period of remarkable growth and learning in their motor repertoire. During early childhood, they gain fundamental movement skills upon which more complex motor skills needed for activities of daily living and participation in physical activity are formed (Gabbard, 2008; Piek, Hands, & Licari, 2012). Children's ability to move also has important implications for their cognitive and social development (Diamond, 2007). The attainment of motor skills provides

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children with new opportunities for learning about their environment, both regarding objects and other individuals (Adolph & Joh, 2007; Von Hofsten, 2009). Being able to act upon their environment allows children to gain knowledge about their surroundings, which leads to changes in various perception-action systems (Von Hofsten, 2009). These changes bring about advances in cognition, both mental and social, which in turn will affect how children examine and manipulate their environment (Campos et al., 2000; Von Hofsten, 2007). The idea that there is a relationship between motor and cognitive development stems in part from the embodied cognition perspective, in which cognition is considered to occur in the context of the individual's bodily interaction with the physical and social environment (Barsalou, 1999; Gibbs, 2005; Oudgenoeg-Paz, Volman, & Leseman, 2012; Smith & Gasser, 2005), a coupling that was also proposed already by Piaget (1952) in his cognitive-developmental theory and by Gibson (1979) in his theory of ecological psychology.

Recent brain data support the theorized association between the two domains (Abe & Hanakawa, 2009; Diamond, 2000; Hanakawa, 2011). Neuroimaging techniques have shown that regions important to motor and cognitive performance, such as the cerebellum, dorsolateral prefrontal cortex, and the connecting structures (including the basal ganglia) are co-activated during motor and cognitive tasks. In addition, motor and cognitive development share a common developmental timetable: e.g., both develop markedly in the preschool period (Howard, Okely, & Ellis, 2015; Piek et al., 2012). Not surprisingly, motor and cognitive problems often co-occur in children with neurodevelopmental disorders (Alloway, 2007; Diamond, 2000; Hellendoorn et al., 2015; Punt, de Jong, de Groot, & Hadders-Algra, 2010). For example, children with motor coordination difficulties, such as Developmental Coordination Disorder (DCD) have been shown to have deficits in certain cognitive processes, known as 'executive functioning' (EF)¹ (Leonard, Bernardi, Hill, & Henry, 2015; Molitor, Michel, & Schneider, 2015; Rahimi-Golkhandan, Steenbergen, Piek, & Wilson, 2014), and vice versa, motor problems have been identified in children with cognitive difficulties (Houwen, Visser, van der Putten, & Vlaskamp, 2016). This, again, is consistent with the notion that motor and cognitive functioning are inter-related.

Despite the different lines of evidence indicating a strong link between motor and cognitive development, a recent review showed that there is little behavioural evidence to support a global-to-global relation between motor and cognitive development in typically developing children (Van der Fels et al., 2015). Instead, support has been found for some distinct associations: results from studies in 4- to 16-year-old children using cross-sectional data have shown associations between specific aspects of motor and cognitive performance, including complex motor skills and higher-order cognitive abilities, i.e., fluid intelligence and visual processing (Van der Fels et al., 2015). With respect to the relationship between motor performance and EF, perhaps the quintessence of higher-order cognitive functioning, strong evidence is still missing for typically developing children (Van der Fels et al., 2015). The few studies that have investigated the relationship between motor performance and EF show inconsistent results (Van der Fels et al., 2015). Looking in more detail to the studies that examined these relationships in typically developing children (e.g., Livesey, Keen, Rouse, & White, 2006; Piek, Dawson, Smith, & Gasson, 2008; Piek et al., 2004; Rigoli, Piek, Kane, & Oosterlaan, 2012; Roebbers & Kauer, 2009; Wassenberg et al., 2005), it appears that adjustment for confounding variables attenuated many of them.

In 7-year old typically developing children, weak-to-moderate correlations were reported between several motor and performance-based EF subtests (e.g., balance and working memory), however, when controlling for age and processing speed only a few of the correlations remained significant (Roebbers & Kauer, 2009). In a 6- to 14-year old normative sample, several weak but significant correlations were found between motor performance and several performance-based EF tasks (i.e., inhibition, working memory, and the ability to plan and respond to goal-directed tasks; Piek et al., 2004). Once variables such as age, gender, and inattention were taken into account, the only EF task that was associated with motor performance was a combined measure of working memory and inhibition. When the impact of early fine and gross motor development was examined in relation to different EF indices at school-age in typically developing children, both working memory and processing speed were found to be predicted by early gross motor development, but not fine motor development, after controlling for gestational age and socio-economic status (SES; Piek et al., 2008). Livesey et al. (2006) found that overall motor performance, and more specifically manual dexterity and ball skills, were moderately to strongly related to performance-based measures of inhibition in typically developing 5- to 6-year-olds. When controlling for age, only manual dexterity was significantly related to inhibition. Another study using a sample of 5- to 6-year old children attending normal kindergarten found that several motor scores (total, quality, and quantity) were related to a performance-based measure of working memory and verbal fluency, which remained significant after controlling for attention. In a normative adolescent sample, weak-to-moderate correlations were found between overall motor performance, manual dexterity, ball skills, and balance and a performance-based measure of inhibition (Rigoli et al., 2012). In addition, significant correlations were found between overall motor performance and ball skills and a performance-based measure of working memory. When controlling for verbal ability and ADHD symptomatology, overall motor performance and ball skills still accounted for a significant proportion of variance in working memory, while only overall motor performance and balance accounted for a significant proportion of variance in the inhibition tasks. These studies provide evidence that several child-related variables may influence the relationship between motor performance and EF in typically developing children.

¹ Although there is still no consensus on the definition of EF, most researchers would agree on the notion that EF encompasses a set of higher-order cognitive abilities, such as inhibition, working memory, and cognitive flexibility, which are instrumental in supporting action control and the flexible adaptation to changing environments (e.g., Karbach & Unger, 2014). The broad definition of EF indicates that the essence of EF is the ability to control behaviour, a concept which is also the foundation of movement and action control (Koziol & Barker, 2013).

The link between motor performance and EF has also been investigated in children with motor coordination difficulties, including children with a diagnosis of DCD. It has been suggested that the association between the motor and cognitive domains might be more evident in children with atypical development than in typically developing children (Dyck, Piek, Hay, Smith, & Hallmayer, 2006; Roebbers & Kauer, 2009) because of abnormal dependences between neurocognitive processes (Dyck et al., 2006; Martin, Tigera, Denckla, & Mahone, 2010). Indeed, a *meta-analysis* including studies of 5–18 year old children with DCD reported clear difficulties in EF across a range of performance-based measures assessing inhibition, working memory, cognitive flexibility, and planning (Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013). In children with motor coordination difficulties but without a formal diagnosis of DCD, similar results have been reported (Leonard & Hill, 2015). Despite several studies suggesting relationships between motor performance and EF in children with motor coordination difficulties, the overall picture is varied (Leonard & Hill, 2015). For example, no significant relationships were found between motor performance and performance-based EF measures of inhibition and planning in either children with DCD or typically developing children, when controlling for age and verbal ability (Pratt, Leonard, Adeyinka, & Hill, 2014), whereas previous research has reported significant correlations between motor skills and measures of response inhibition in normative samples (e.g., Livesey et al., 2006; Piek et al., 2004; Rigoli et al., 2012). Different paradigms have been used to measure different forms of inhibition, including motor response inhibition and interference control (Nigg, 2000). The chosen tasks differ with respect to their specific motor and cognitive demands and may therefore lead to different results. Hence, the mixed results may be due to methodological differences and tasks measuring different aspects of EF (Leonard & Hill, 2015). If so, it is especially problematic since the dynamic nature (i.e., fluctuating course) of development already complicates the rigor of the studies in this field. Moreover, recent developmental work has revealed the existence of a developmental coupling between motor and cognitive operations over the course of childhood (Ruddock et al., 2016). This study showed that the coupling of inhibitory control (using performance-based measures) and online motor control emerges gradually, and is delayed in children with DCD (Ruddock et al., 2016).

The available literature on the relationship between motor performance and EF shows a number of issues needing to be addressed. First the vast majority of the studies investigating the relationship between motor performance and EF have focused on children aged five years and older. Empirical research concentrating on this relationship in preschool children (i.e., age 3–5 years) is still rare (Niederer et al., 2011), which is surprising since the preschool years have been identified as a particularly crucial time in the emergence and development of both motor skills and EF (Howard et al., 2015; Piek et al., 2012). Further studies are thus needed to examine whether relationships exist in younger samples. Another important issue to consider is the level of motor skill proficiency of children (Rigoli et al., 2012; Wassenberg et al., 2005). Rigoli et al. (2013) suggested that whether or not a relationship exists between motor performance and EF may depend on the following factors: the assumed direction of the relationship, the developmental level (age) of the child, and the presence of motor coordination difficulties. Thus, when studying the relationship between motor performance and EF in young children, the full range of motor skill proficiency (i.e., children with age-typical motor skills as well as children who meet diagnostic criteria for DCD) should be taken into account (Geuze, Schoemaker, & Smits-Engelsman, 2015).

Furthermore, the operationalization and measurement of EF, specifically performance-based measures versus parent ratings of EF, is an important issue that directly impacts the inferences that can be made about these competencies (Leonard & Hill, 2015; Toplak, West, & Stanovich, 2013). There is mounting evidence that performance-based measures and parent ratings of EF do not assess the same construct (Toplak et al., 2013), but that they may provide complementary information (Campbell et al., 2016; Isquith, Roth, & Gioia, 2013). While performance-based EF measures typically assess specific, individual executive functions under highly structured and standardized conditions (Toplak et al., 2013), rating scales of EF, such as the Behaviour Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000), were developed to tap into complex, real-world manifestations of executive functions (Toplak et al., 2013). It has been suggested that the type of EF measurement may affect the relationship between motor performance and EF (Ten Eycke & Dewey, 2015), because both types of measures capture different levels of underlying mental constructs (i.e., performance-based measures capturing efficiency of information processing and rating measures capturing success in goal pursuit; Toplak et al., 2013). As the majority of studies investigating the relationship between motor performance and EF have been based primarily on performance-based measures, it is unclear if and how motor performance may be related to observations of EF in an everyday context. Addressing this issue is particularly relevant in early childhood, where assessment of EF by performance-based measures is a challenge, as validated tests are relatively few, norms are uncertain, and variables as limited attention span, motivation, and confidence in the testing situation might influence the results (Nilsen, Huyder, McAuley, & Liebermann, 2016). Finally, the possible role of confounding variables should be taken into account, as multiple studies (included above) show that many relationships between motor performance and EF are attenuated when other variables are included in the analysis.

The present study examined the relationship between motor performance and EF in young children with different levels of motor skill proficiency, including typically developing children and children at risk for motor coordination difficulties,² while controlling for potentially confounding variables such as age, gender, SES, and ADHD symptomatology. These confounding variables have been previously identified in the literature as being associated with either motor performance, EF, or both (e.g., Huizinga & Smidts, 2011; Klein, Fröhlich, Pieter, & Emrich, 2015; Missiuna & Campbell, 2014; Mulder, Hoofs, Verhagen, van der

² Since a diagnosis of DCD is not recommended before the age of 5 (Blank, Smits-Engelsman, Polatajko, & Wilson, 2012), we identified children who were at risk for motor coordination difficulties. A moderately stringent criterion of impaired performance at or below the 16th percentile for impairment was used rather than the 5th percentile.

Veen, & Leseman, 2014; Rigoli et al., 2012). Based on the theoretical and neurodevelopmental literature, we hypothesized that motor performance would, in general, have positive relations with EF. Given the limited and mixed research literature, it is still unclear which motor skills and executive functions would be most strongly associated with each other. The dynamic nature (i.e., fluctuating course) of motor and EF development in young children poses an extra challenge for generating clear predictions regarding the precise nature of relationships between both domains in preschool children. Hence, no specific hypotheses were formed, and the focus of the present study is mainly exploratory.

2. Method

2.1. Participants

Recruitment occurred through primary schools, kindergartens, paediatric physical therapy practices and through public advertisements and snowballing techniques. Children aged 3;0 to 5;11 years were eligible for inclusion. A parent-report questionnaire was used to ascertain the absence of physical disabilities, neurological disorders (e.g., intellectual disability or autism spectrum disorder), and sensory impairments. The parents of 163 children responded and consented to the project; however four children were excluded from the final analyses because of suspected or diagnosed Autism Spectrum Disorder. In addition, six children were excluded because they had incomplete motor assessment or EF data. This resulted in a sample of 153 children (75 boys, 78 girls) with a mean age of 4 years 1 month (SD 8 months). Given our recruitment procedure, the sample was somewhat weighted towards those with motor coordination difficulties and hence the motor scores span a wide range of ability.

No child had a parent-reported formal diagnosis of DCD, but 22 children were in treatment with a paediatric physiotherapist for a motor development concern, scored at or below the 16th percentile on the Movement Assessment Battery for Children-2, Dutch Version (MABC-2; Henderson, Sugden, Barnett, & Smits-Engelsman, 2010), and had functional problems as reported by parents in the Little Developmental Coordination Disorder Questionnaire (Rihtmman, Wilson, & Parush, 2011). Furthermore, no child had a parent-reported formal diagnosis of ADHD but subclinical symptoms of this disorder were taken into account; see analyses.

The study was approved by the Ethics Committee of the Department of Pedagogical and Educational Sciences, Faculty of Behavioural and Social Sciences, University of Groningen. Informed written consent was obtained from parents/guardians.

2.2. Measurement of study variables

2.2.1. Motor performance

Motor performance was assessed with the MABC-2 (Henderson et al., 2010). This test consists of three sections: Manual Dexterity (three items), Aiming and Catching (two items), and Balance (three items). The raw scores of each item can be recoded into an item standard score and summed into a total standard score (range 1–19, mean score = 10, SD = 3) and percentile score. In accordance with the MABC-2 guidelines, children falling at or below the 16th percentile were classified as being at risk for motor coordination difficulties; children above the 16th percentile were considered typically developing.

The psychometric properties of the MABC-2 suggest that it is a valid and reliable measure to be used in young children (Ellinoudis et al., 2011; Psotta & Brom, 2016; Smits-Engelsman, Niemeijer, & van Waelvelde, 2011).

2.2.2. Executive functioning

Parents completed the Dutch translation of the Behaviour Rating Inventory of Executive Function–Preschool version (BRIEF-P; Gioia, Espy, & Isquith, 2005), a 63-item standardized rating scale that assesses different aspects of EF in children 2;0–5;11 years. The primary caregivers were asked to rate how often their child exhibited various behaviours related to EF in the past 6 months on a 3-point scale (1 = never, 2 = sometimes, 3 = often). Five theoretically and empirically derived scales were used to measure children's abilities with respect to the following aspects of EF: (1) Inhibition, 16 items assessing the child's ability not to act upon impulse (e.g., "Acts out of control"); (2) Shifting, 10 items measuring rigidity or inflexibility (e.g., "Has trouble changing activities"); (3) Emotional Control, 10 items assessing emotional responses to seemingly minor events (e.g., "Mood changes frequently"); (4) Working Memory, 17 items measuring ability to hold information in mind for the purpose of completing a task (e.g., "Has trouble remembering, even after a short amount of time"); (5) Planning/Organize, 10 items assessing ability to anticipate future events and bring order to information, actions, or materials in order to achieve a goal (e.g., "Puts things away in a random, disorganized way when cleaning up"). The Global Executive Composite (a sum score of the five clinical scales) is a total measure of EF. Raw score totals for each scale are converted to age- and sex-specific *T*-scores (mean of 50, SD of 10) in which higher scores indicate greater executive dysfunction. *T*-scores of 65 and above are considered clinically significant.

The Dutch version of the BRIEF-P (Van der Heijden, Suurland, De Sonnevle, & Swaab, 2013) showed sufficient to high internal consistency, test-retest reliability, interrater reliability, and construct validity. Furthermore, it showed adequate convergent discriminant and predictive validity. Research using the BRIEF-P has shown that it is a reliable and valid measure of EF in the preschool period (Ezpeleta, Granero, Penelo, de la Osa, & Domènech, 2015; Skogan et al., 2016). The derived dimensions obtained satisfactory internal consistency, moderate convergent validity with psychopathology and

temperament, and good ability to discriminate between clinical groups and typically developing children (Ezpeleta et al., 2015). The results from a recent study suggested that it may also be sensitive to individual variability in the typical preschool development of EF (Garon, Piccinin, & Smith, 2016).

2.2.3. Confounding variables

A series of potential confounders previously identified in the literature as being associated with either motor performance, EF, or both, were included in the analyses. Child-related confounding variables comprised age, gender, and ADHD symptomatology. ADHD symptomatology was assessed with the 5-item Hyperactivity-Inattention subscale of the Strengths and Difficulties Questionnaire3–4 (SDQ3–4; Goodman, 1997), which displays acceptable psychometric properties in pre-schoolers (Croft, Stride, Maughan, & Rowe, 2015; Doi, Ishihara, & Uchiyama, 2014; Theunissen, Vogels, de Wolff, & Reijneveld, 2013). The items were “Restless, overactive”, “Constantly fidgeting”, “Easily distracted”, “Can stop and think things out before acting”, and “Sees tasks through to the end”. Items were coded on a 3-point scale (0 = not true, 1 = sometimes true, and 2 = certainly true) with reverse coding for the two last items. An environmental confounding variable was SES. The three most commonly used indicators of SES are educational level, income, and occupation (Hoff, Laursen, & Bridges, 2012; Winkleby, Jatulis, Frank, & Fortmann, 1992), with maternal education being one of the strongest indicators of SES in studies of child development (Hoff et al., 2012). In this study, maternal educational level was used as an indicator of children’s SES because several studies found maternal educational level to be a significant determinant of children’s EF (e.g., Ardila, Rosselli, Matute, & Guajardo, 2005; Arán-Filippetti & Richaud de Minzi, 2012). Maternal educational level was classified into three groups: ‘low educational level’ (primary school and lower secondary education), ‘intermediate educational level’ (intermediate vocational level, higher secondary school and pre-university education), and ‘high educational level’ (higher vocational education and university).

2.3. Procedure

All children were individually tested on the MABC-2 by extensively trained assessors. Test duration lasted between 25 and 45 min. The questionnaires were usually completed by the accompanying mother in the same room at the same time their child was tested.

2.4. Data analysis

We analysed the results using IBM SPSS Statistics 23. Our research aim was focused on the relationship between motor performance and EF. Bivariate associations among the criterion variables, predictors, and control variables were explored with Pearson’s correlations. A series of hierarchical regression analyses were conducted to determine whether the MABC-2 Total Score or its component scores (manual dexterity, aiming and catching, and balance) accounted for incremental variance in each of the BRIEF-P subscales, after controlling for confounding variables (age, gender, SES, and, ADHD symptomatology). Prior to conducting the analyses assumptions of normal distribution, linearity, and homoscedasticity were tested. In the first step, the confounding variables age, gender, SES, and ADHD symptomatology were entered. In the second step, motor performance was added. To give insight into the independent result of motor performance, the betas from the final model are reported in the text and in Table 3. The significance of the final models were considered in light of Bonferroni-corrected values for multiple comparisons ($p = 0.01$).

The most complex regression model included three control variables and three primary predictors. Our sample size of 153 was sufficient to detect moderate relationships between the criterion variables and the primary predictors (Faul, Erdfelder, Buchner, & Lang, 2009).

3. Results

3.1. Descriptives

Table 1 shows the means, standard deviations, and ranges for the study variables. In the current sample MABC-2 percentile scores ranged from 0.1 to 98.0, with 49 (32%) children falling into the ‘motor coordination difficulties’ risk category (≤ 16 th percentile on the MABC-2).

3.2. Bivariate correlations

Bivariate correlations between criterion variables, predictors, and control variables were calculated on the total sample of 153 children. These results are presented in Table 2. The Working Memory subscale and Planning/Organize subscale were weakly to moderately correlated to the Manual Dexterity subtest, Aiming & Catching subtest, and the MABC-2 Total Score. In addition, the Inhibition subscale had a weak correlation with the Aiming & Catching subtest and the Shifting subscale a weak correlation with the MABC-2 Total Score. Age significantly correlated with all the MABC-2 scores (except for the Balance subtest), whereas for the EF scores it correlated only with the Shifting subscale. Gender was related only to

Table 1

Means, SDs, and range of scores for the study variables.

	Mean	SD	Range
Age	4;1	0;8	3;0 – 5;11
<i>MABC-2-NL</i>			
Manual dexterity ^a	9.5	3.4	1–19
Aiming and catching ^a	9.3	3.0	1–19
Balance ^a	8.7	3.3	1–18
Total Score ^a	8.8	3.5	1–16
<i>BRIEF-P</i>			
Inhibition ^a	52.4	11.6	35–92
Shifting ^a	52.6	12.8	37–106
Emotion Regulation ^a	52.8	11.9	39–86
Working Memory ^a	53.3	11.7	36–88
Plan/Organize ^a	53.1	11.2	36–85
<i>SDQ</i>			
Hyperactivity/inattention ^b	3.3	2.4	0–10
SES			
Low SES	5		
Intermediate SES	37		
High SES	58		

Note. MABC-2 = Movement Assessment Battery for Children-2; BRIEF-P = Behaviour Rating Inventory of Executive Function – Preschool

^a Age-standardized score.

^b Raw score.

Table 2

Zero-order correlation matrix for the key and control variables.

	2	3	4	5	6	7	8	9	10	11	12	13
1. age	0.10	0.20 [*]	–0.17 [*]	–0.25 ^{**}	–0.26 ^{**}	–0.20 [*]	–0.13	0.07	0.17 [*]	0.15	0.05	0.03
2. sex		0.19 [*]	0.08	–0.16	–0.13	0.05	–0.22 ^{**}	–0.06	0.02	0.00	–0.09	–0.04
3. SDQ3–4			–0.20 [*]	–0.28 ^{**}	–0.25 ^{**}	–0.23 ^{**}	–0.09	0.68 ^{***}	0.56 ^{***}	0.68 ^{***}	0.60 ^{***}	0.50 ^{***}
4. SES				0.19 [*]	0.17 [*]	0.14	0.17 [*]	–0.24 ^{**}	–0.09	–0.10	–0.28 ^{**}	–0.26 ^{**}
5. MABC-2 Total Score					0.81 ^{***}	0.70 ^{***}	0.74 ^{***}	–0.15	–0.21 [*]	–0.13	–0.34 ^{***}	–0.22 ^{**}
6. MABC-2 Manual Dexterity						0.45 ^{***}	0.47 ^{***}	–0.12	–0.12	–0.04	–0.28 ^{**}	–0.20 [*]
7. MABC-2 Aiming and Catching							0.33 ^{***}	–0.17 [*]	–0.11	–0.15	–0.26 ^{**}	–0.22 ^{**}
8. MABC-2 Balance								0.02	–0.12	–0.01	–0.15	–0.06
9. BRIEF-P Inhibition									0.42 ^{***}	0.64 ^{***}	0.68 ^{***}	0.59 ^{***}
10. BRIEF-P Shifting										0.68 ^{***}	0.48 ^{***}	0.46 ^{***}
11. BRIEF-P Emotion Regulation											0.47 ^{***}	0.40 ^{***}
12. BRIEF-P Working Memory												0.80 ^{***}
13. BRIEF-P Plan/Organize												

Note: SDQ3–4 = Strengths and Difficulties Questionnaire3–4; SES = socio-economic status; MABC-2 = Movement Assessment Battery for Children-2; BRIEF-P = Behaviour Rating Inventory of Executive Functioning – Preschool.

^{*} $p < 0.05$.

^{**} $p < 0.01$.

^{***} $p < 0.001$.

performance on the Balance subtest, where girls performed better than boys. ADHD symptomatology was found to correlate with all the motor and EF measures, except for the Balance subtest.³ In all cases, children with higher hyperactivity/inattention scores had poorer performance on the MABC-2 and the BRIEF-P. SES correlated significantly with the Manual Dexterity subtest, the Balance subtest, the MABC-2 Total Score, the Inhibition subscale, the Working Memory subscale, and Planning/Organize subscale, indicating that children with a lower SES had poorer scores on the motor and EF measures.

³ These correlations of main interest were still significant if Bonferroni corrections for multiple comparisons were applied. Bonferroni corrections were not applied on the entire correlation matrix in order not to inflate type II error probability, and not to increase the risk of failing to detect possibly important predictors that should be accounted for in the subsequent regression analyses.

3.3. Multiple linear regression analyses

Hierarchical multiple regression analyses were used to assess the relative contribution of the key variables. As expected, there were strong correlations between the MABC-2 Total Score and each of its components (see Table 2). Because the MABC-2 Total Score was a reliable predictor of the component scores, it was included as a proxy for the component scores in the analysis, thereby reducing the complexity of the regression model and optimizing statistical power. Age, gender, SES, and ADHD symptomatology were entered first, followed by the MABC-2 Total Score. Table 3 summarizes information for Step 2 of each regression analysis, with all predictors included in the models.

After controlling for the four covariates, the MABC-2 Total Score explained a significant 3.4% of the variance in the Working Memory subscale ($\beta = 0.20$; $p = 0.003$). The total model accounted for 47.9% of the variance. The MABC-2 Total Score did not explain additional variance in the Inhibition subscale ($\beta = 0.02$; $p = 0.740$), the Shifting subscale ($\beta = -0.12$; $p = 0.176$), the Emotion Regulation subscale ($\beta = -0.00$; $p = 0.967$), and the Planning/Organize subscale ($\beta = -0.10$; $p = 0.209$).⁴

3.4. Typically developing versus at risk for motor coordination difficulties

A MANCOVA was conducted to examine the difference between the two groups on the EF subscales. Covariates were age, sex, SES, and ADHD symptomatology. The main effect of group was statistically significant [$F(5, 139) = 3.33$, $p = 0.007$]. Each dependent variable was examined using univariate ANCOVA. Statistically significant differences were found for the Working Memory subscale [$F(1, 143) = 10.13$, $p = 0.002$] and the Planning/Organize subscale [$F(1, 143) = 4.55$, $p = 0.035$], indicating that the children at risk for motor coordination difficulties had worse EF performance than the typically developing group. No significant differences were found for the Inhibition subscale ($p = 0.463$), the Shifting subscale ($p = 0.510$), and the Emotion Regulation subscale ($p = 0.490$).

As a group, the mean *T*-scores for children at risk for motor coordination difficulties were below 65 for all subscales. However, when looking at individual data, significantly more children in this group had *T*-scores in the clinically significant range for both the Working Memory ($\chi^2 = 6.64$, $p = 0.022$) and the Planning/Organization subscales ($\chi^2 = 5.92$, $p = 0.027$), compared to the typically-developing group.

4. Discussion

4.1. Main findings

The primary issue investigated in this study was whether motor performance was related to parent-reported EF in pre-school children and whether this relationship still holds when possible confounding variables are accounted for. Several significant, albeit weak to moderate, relationships were found between motor performance and the EF subscales. Once other variables such as age, gender, SES, and ADHD symptomatology were taken into account, the only EF subscale that was associated with the MABC-2 Total Score was the Working Memory subscale. Compared to their typically developing peers, children who are at risk for motor coordination difficulties showed significantly lower scores on the Working Memory subscale, which confirms the results of the regression analyses. The at risk group also performed significantly worse on the Planning/Organize subscale, however. In the current study, ADHD symptomatology seemed to play an important role in the relationship between motor performance and parent-reported EF already in early childhood.

Prior studies on the relationship between motor performance and EF in normative samples have mainly focused on two “core” EF functions, namely working memory and inhibition (e.g., Livesey et al., 2006; Piek et al., 2004; Rigoli et al., 2012). These studies found significant but mainly weak associations between motor performance and the aforementioned EF domains, when controlling for confounding variables such as age and ADHD symptomatology. Our results with preschool age children are consistent with these findings in that working memory performance was predicted by motor performance, but our results fail to support the idea that motor performance exerts an influence on inhibition. The three additional aspects of EF we examined, that is, shifting, emotion regulation, and planning/organize in relationship to motor performance, were also unrelated to motor performance at this age. It is plausible that the nature of the relationship between motor performance and EF at this young age (3–5 years) is different from what is found in older children (Pratt et al., 2014; Rigoli et al., 2013). Although there is marked overall development of EF during childhood (Best & Miller, 2010), the rate of this improvement may vary considerably between executive functions and also between children (Van der Ven, Kroesbergen, Boom, & Leseman, 2012). In addition, several authors have postulated the idea that only some executive functions are related to motor performance and argue against the notion of a global relationship between motor and cognitive development, because of specific specialized processes underlying different motor skills and executive functions (Stöckel & Hughes, 2015; Wassenberg et al., 2005). Indeed, our and earlier results (e.g., Stöckel & Hughes, 2015; Wassenberg et al., 2005) do not support the theoretical assumption, raised by Piaget (1952) in his cognitive-developmental theory, of a direct linkage between global aspects of motor and cognitive development.

⁴ Even with corrected alpha level of $p = 0.01$ to account for the fact that five regression analyses were performed, all significant predictors remained significant.

Table 3

Summary details of the hierarchical regression analyses predicting performance on each BRIEF-P subscale.

EF variables	Predictors	B	SE B	β	t	p	Adj. R ²	ΔR^2
Inhibition	Age	0.01	0.07	0.01	0.17	0.866		
	Gender	−4.21	1.48	−0.18	−2.84	0.005*		
	SES	−0.40	1.34	−0.02	−0.30	0.764		
	ADHD symptomatology	3.26	0.33	0.68	9.92	0.000*		
	MABC-2	0.07	0.22	0.02	.33	0.740	0.431*	0.000
Shifting	Age	0.15	0.10	0.12	1.48	0.140		
	Gender	−1.61	2.08	−0.06	−0.78	0.440		
	SES	0.84	1.88	0.04	.45	0.655		
	ADHD symptomatology	1.50	0.46	0.28	3.25	0.001*		
	MABC-2	−0.42	0.31	−0.12	−1.36	0.176	0.095*	0.011
ER	Age	0.14	0.09	0.12	1.53	0.128		
	Gender	−2.02	1.89	−0.09	−1.07	0.287		
	SES	0.92	1.71	0.04	.54	0.592		
	ADHD symptomatology	1.93	0.42	0.39	4.57	0.000*		
	MABC-2	−0.01	0.28	−0.00	−0.04	0.967	0.129*	0.000
WM	Age	−0.06	0.07	−0.06	−0.91	0.369		
	Gender	−5.23	1.46	−0.22	−3.58	0.000*		
	SES	−1.08	1.32	−0.06	−0.82	0.414		
	ADHD symptomatology	2.94	0.32	0.60	9.07	0.000*		
	MABC-2	−0.67	0.22	−0.20	−3.04	0.003*	0.461*	0.034*
Plan/Organize	Age	−0.06	0.08	−0.06	−0.80	0.427		
	Gender	−2.97	1.59	−0.13	−1.87	0.064		
	SES	−1.77	1.44	−0.09	−1.23	0.221		
	ADHD symptomatology	2.36	0.35	0.51	6.67	0.000*		
	MABC-2	−0.31	0.24	−0.10	−1.27	0.209	0.294*	0.008

Note: For each regression, age, gender, SES, and ADHD symptomatology were entered at Step 1 (note that this step of each model is not shown). The MABC-2 Total Score was entered at Step 2. The total adjusted R² accounted for by the final model and the change (Δ) in R² for Step 2 are provided, as are standardized beta values, unstandardized coefficients, and standard errors for each of the predictors along with significance values. Significance is denoted in bold with an asterisk (a Bonferroni correction of $p = 0.01$ is applied to the total model). MABC-2 = Movement Assessment Battery for Children-2; ER = Emotion Regulation; WM = Working Memory.

It is also possible that the discrepancy between our results and those of previous studies arise from methodological issues related to the measures used to assess EF. In our study, we used a parent-report measure rather than experimental tests of EF used in other studies (e.g., Leonard et al., 2015; Livesey et al., 2006; Piek et al., 2004; Rigoli et al., 2012). Parent ratings of early executive functions are likely to capture other aspects of EF than do performance-based measures. Performance-based measures are developed to assess the specific cognitive processes implicated in EF (i.e., cognitive component of EF), whereas parent ratings reflect how these processes play out in real-world natural settings (i.e., behavioural component of EF; Mahone, Martin, Kates, Hay, & Horská, 2009; Toplak et al., 2013). It has been shown in school-age children that the two assessment methods are differentially associated with motor performance (Ten Eyck & Dewey, 2015). Thus, our results do not preclude the existence of an association between motor performance and EF as measured by performance-based tests in this age group.

In the present study, we found that the children at risk for motor coordination difficulties displayed significantly worse performance in working memory and planning/organize in everyday life than the typically developing children, independent of age, gender, SES, and ADHD symptomatology. In addition, the frequencies of EF impairment were significantly higher in the children at risk for motor coordination difficulties for the Working Memory and Planning/Organize subscales. In contrast, no group differences were found in inhibition, shifting, and emotion regulation. These results suggest that preschool children at risk for motor coordination difficulties had “specific” impairments rather than a “global” EF impairment. The poorer performance on working memory and planning/organize is in line with current literature using performance-based EF tests, reporting that children with a diagnosis of DCD and children with motor coordination difficulties show deficits in working memory and planning (Alloway, 2007; Leonard et al., 2015; Pratt et al., 2014; Wilson et al., 2013). Similarly to our study, Toussaint-Thorin et al. (2013) showed that in a sample of 8- to 12-year old children with developmental dyspraxia difficulties were predominant in the Working Memory and Planning subscales of the BRIEF, whereas performance on the Inhibition subscale was less impaired. In contrast to our findings, children with DCD are reported to display more problems in inhibition, shifting, and emotion regulation than their typically developing peers (Leonard et al., 2015; Piek, Dyck, Francis, & Conwell, 2007; Pratt et al., 2014; Rahimi-Golkhandan, Piek, Steenbergen, & Wilson, 2014; Rahimi-Golkhandan,

Steenbergen et al., 2014) although in one study no differences were found for shifting (Leonard et al., 2015). Some researchers have indicated that EF deficits in children with DCD are more likely for tasks with a motor and/or visuospatial load (Leonard et al., 2015; Wilson et al., 2013) and, as such, may explain some differences between our results (based on behavioural EF in everyday contexts) and more experimental tasks. However, the complication is that EF deficits are not always more apparent in tasks with a motor and/or visuospatial load. For example, a study examining inhibition using separate verbal and motor tasks demonstrated that children with DCD produced more errors in a motor inhibition task but were also slower at inhibiting a verbal response (Bernardi, Leonard, Hill, & Henry, 2016). In addition, it has been shown that aspects of everyday (working) memory may be mediated by verbal intelligence (Chen, Tsai, Hsu, Ma, & Lai, 2013).

The exact mechanisms behind the relation between motor performance and EF are so far unknown. On a neuroanatomical basis, the co-activation of brain areas such as the cerebellum, the dorsolateral prefrontal cortex, and the connecting structures (including the basal ganglia) explains the relationship between motor and cognitive functioning (Diamond, 2000). Although a relationship between motor and cognitive processes can be found in typically developing and atypically developing samples due to shared neural substrates and neurological integrity in general, stronger associations between developmental domains are expected in children with atypical development reflecting abnormal dependences between neurocognitive processes (Dyck et al., 2006; Martin et al., 2010). Magnetic resonance imaging research on children with DCD has shown that in comparison with controls, children with DCD activate regions of the brain differently during functional tasks compared to typically developing children (Brown-Lum & Zwicker, 2015). For example, a study showed that children with DCD demonstrated a different pattern of activation from typically developing peers in the dorsolateral prefrontal cortex, inferior parietal lobule, and the cerebellum (Zwicker, Missiuna, Harris, & Boyd, 2011). These findings might help us understand why weak results on EF tasks are associated with poorer results on motor tasks and vice versa. Further research into DCD provides an opportunity for investigating potential shared mechanisms underlying motor and EF processes, as well as their neural correlates, in both typical and atypical development (Leonard, 2016).

An alternative account is provided by Luo, Jose, Huntsinger, and Pigott (2007). They have argued that family characteristics and parenting practices are environmental factors similarly affecting motor and cognitive development. Hence, early recognition and the influence of environmental factors need to be taken into account when examining motor and cognitive development (Smits-Engelsman & Hill, 2012). So, it is also important to acknowledge the role of individual experiences on the relationship between motor performance and EF.

4.2. Strengths and limitations

The study's most important strength is that it includes a large sample with a fairly equal gender representation, and a narrow age range that is rarely studied with regard to the relationship between motor performance and EF. The study has also some limitations that need to be considered. First, our recruitment procedure involved oversampling children with motor coordination difficulties, in order to maximize the variance in our sample. Because recruitment occurred partly through paediatric physical therapy practices, we were able to include 14% of children in our sample that could be regarded as being at risk for DCD. However, an additional 18% of children scored below the 16th percentile. This percentage is higher than one would expect in a normative sample. Our recruitment strategy might have attracted parents who were concerned about the performance of their child. However, it is also important to note that development is highly variable in young children and, therefore, it has been recommended to retest young children when they score poorly on the MABC-2 (Smits-Engelsman et al., 2011). While none of the children in our sample have a clinically diagnosed developmental disorder, it is possible that this sampling method could bias the results if there are discontinuities between typical and atypical development (Kenny, Hill, & Hamilton, 2016). Second, we did not include an objective measure of the IQ of the children. However, all parents indicated on the demographic questionnaire that no intellectual disability was present. Furthermore, all children were able to understand the test instructions when performing the MABC-2. Third, although we included a range of confounding variables, it is important, in attempting to interpret the results of the present study, to note that other variables that were not taken into account in the present study may have played a role. That behaviour and its development are multiply determined is a cornerstone of dynamic systems theory (Thelen & Smith, 1994). The dynamic systems theory proposes that multiple systems contribute to child development and that environmental and task factors interact with individual characteristics in determining development. One of these individual characteristics may be the temperament of the child. Temperamental differences relate to the way in which children are allowed and encouraged to engage in physical and social play (Diamond, 2013; Tucker et al., 2009), which may in turn impact motor and EF development.

A fourth limitation of the present study is that the data are cross-sectional, which limits causal inferences. There is increasing evidence of intraindividual and interindividual variation across early childhood development, which emphasizes the importance of using longitudinal assessment of development. Future studies should therefore include prospective, multiple time point assessments of motor performance and EF to more fully understand the dynamic interplay between both domains across development and how the developing relationships are mediated by child- and environment related variables. There is some evidence that early motor development predicts later performance on complex cognitive tasks including working memory (Murray, Jones, Kuh, & Richards, 2007; Piek et al., 2008; Ridler et al., 2006).

Finally, the parent report methodology with regard to EF (BRIEF-P) and ADHD symptomatology (SDQ3–4) was both a strength and a limitation of this study. Parents' rating may be influenced by personal biases, beliefs, and prior experiences. For example, parent ratings of both EF and ADHD symptomatology may introduce bias due to shared response bias in parent

perception, that is, viewing a child's skills as uniformly negative or positive. The strong association between scores on the BRIEF-P and SDQ3-4 in the present study must be interpreted bearing in mind that assessment of EF and ADHD symptomatology were both based on parent report. In a previous study with older children, parent-reported ADHD symptoms from the SDQ were not significant predictors of any performance-rated measure of EF (Leonard et al., 2015). Parent ratings of EF may also be biased or skewed by other factors, such as parental mental health (Loe, Chatav, & Alduncin, 2015). Although it could be argued that it may be hard for parents to identify whether certain behaviours are typical for a child of the same age as their own child, or clinically-relevant, several recent studies confirmed that the parent-rated BRIEF-P and SDQ3-4 are reliable and valid instruments for preschoolers and are recommended for screening purposes (e.g., Croft et al., 2015; Garon et al., 2016). To improve the practical (ecological) validity of future studies, a combination of parent and teacher-rated behaviour would be an option. In addition, the BRIEF-P assesses many EF skills broadly and consequently does not obtain detailed, in-depth information on any of the executive functions it assesses. Therefore, future studies should use both parent-ratings and performance-based measures of EF to gain more insight in the relationship between motor performance and EF in preschoolers. The majority of authors studying both parent ratings and performance-based EF measures have argued that each approach is important, capturing divergent but related information (Skogan et al., 2015).

4.3. Practical implications

Our findings provide evidence that specific EF skills are already at risk in preschool-age children with motor coordination difficulties. This is a highly significant finding because it indicates that the emergence of several specific EF deficits occurs at substantially younger ages than have been investigated in past research. The implication is that monitoring and tracking of these critical areas of developmental risk should begin at a young age. In addition, our data and earlier studies of EF in children with motor difficulties, including children with DCD (e.g., Leonard et al., 2015; Rahimi-Golkhandan, Steenbergen, Piek, Caeyenberghs, & Wilson, 2016) suggest that it is prudent to provide interventions and support that boost both motor and EF development. Research has shown that task-orientated motor skill interventions are most effective in improving motor skills in children with DCD (Preston et al., 2016). But despite theoretical and practical links between motor and EF in children with motor coordination difficulties, very little research has been done into the effects of motor skill-related interventions on EF in these children. However, there is promising evidence of beneficial effects of motor coordination training during development (Chang, Tsai, Chen, & Hung, 2013; Koutsandréou, Wegner, Niemann, & Budde, 2016; Pesce et al., 2016). Pesce et al. (2016) showed that movement games, centred on deliberate play and capitalising on cognitive stimulation by variable task demands, provide a unique form of stimulation that impacts children's EF. In a recent commentary, Pesce et al. (2016) propose that novelty, diversity, effort, feeling of successfulness, and enjoyment are essential ingredients for an effective intervention for children. To stimulate EF development by movement activities, cognitive challenges should be embedded into emotionally loaded playful activities (Diamond & Lee, 2011) and at the same time adequate to a child's level of skill development (Pesce et al., 2013). The presence of EF deficits supports the use of new types of training environments and teaching strategies in children with motor coordination difficulties where coordinative and cognitive tasks requirements are such that they stimulate both motor and EF development but do not place excessive demands on executive functions such as working memory in order not to disadvantage the child with motor coordination difficulties (Pesce et al., 2013; Wilson et al., 2013). Notably, computer-based games, simulations and mixed-reality have been shown to be useful in engaging the attention of children with DCD and CP, motivating effort, and developing skills (e.g., Jelsma, Geuze, Mombarg, & Smits-Engelsman, 2014; Mumford, Duckworth, & Wilson, 2015; Wilson, 2014; Wilson, Green, Caeyenberghs, Steenbergen, & Duckworth, 2016).

In addition to suggesting new priorities for intervention, these results should spur new developmental and neuroscience research that links these early skills through causative mechanisms to later achievement. Studies over the past 10 years have provided substantial support for significant contributions of motor development and EF to later academic achievement. Building stronger theories and knowledge about the interrelationships among motor skills and EF, and the potential causative mechanisms that might link them to later achievement can result only in better design and increased power and efficiency of interventions.

5. Conclusion

This is one of the first studies investigating the interrelationship among motor performance and parent-rated EF in such a young age group. It shows that the relationship between motor performance and EF in young children is complex and may be influenced by the presence of confounding variables such as ADHD symptomatology.

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